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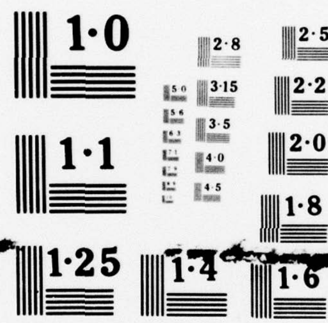

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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

THE EFFECT OF COOLING AIR ON THE AERODYNAMIC CHARACTERISTICS OF TURBINE NOZZLE CASCADES

by

L. L. Ginzburgskiy, Yu. S. Podobuyev,
K. G. Rodin

FOREIGN TECHNOLOGY DIVISION

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EDITED TRANSLATION

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By L. L. Ginzburgskiy, Yu. S. Podobuyev, K. G. Rodin

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Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
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К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

GREEK ALPHABET

Alpha	Α α *α*		Nu	Ν ν	
Beta	Β β		Xi	Ξ ξ	
Gamma	Γ γ		Omicron	Ο ο	
Delta	Δ δ		Pi	Π π	
Epsilon	Ε ε *ϵ*		Rho	Ρ ρ *ϱ*	
Zeta	Ζ ζ		Sigma	Σ σ *ς*	
Eta	Η η		Tau	Τ τ	
Theta	Θ θ *ϑ*		Upsilon	Τ υ	
Iota	Ι ι		Phi	Φ φ ϕ	
Kappa	Κ ϰ κ *ϰ*		Chi	Χ χ	
Lambda	Λ λ		Psi	Ψ ψ	
Mu	Μ μ		Omega	Ω ω	

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}

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rot	curl
lg	log

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THE EFFECT OF COOLING AIR ON THE AERODYNAMIC CHARACTERISTICS OF TURBINE NOZZLE CASCADES

L.L. Ginzburgskiy, Yu.S. Podobuyev, K.G. Rodin

For gas turbines only blades with the output of the cooling air near the outlet edge are used for gas turbines. Jets of cooling air coming out of openings affect the aerodynamic characteristics of the nozzle cascade. To investigate this effect, an experimental installation with a ring cascade was assembled at the Department of Turbine Construction. A natural nozzle cascade of the gas turbine was installed on this installation. The velocity field of the flow behind the cascade was investigated with respect to the pitch and height of the blades with a change in the relative flow rate of the cooling air.

The traversing of the flow at the outlet from the cascade was produced by a three-channel probe. The flow rate of the cooling air through the outlet openings was determined by the equation

$$G_{\text{охл}} = m\frac{p^*_{ш} F_{ш} q(\lambda_{ш})}{\sqrt{T^*_{ш}}},$$

where

$$m = \sqrt{\frac{k}{R}\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}};\quad \Pi(\lambda_{ш}) = \frac{p_{ш}}{p^*_{ш}},$$

here $q(\lambda_{ш})$ is the normalized density of the flow of mass through the slot; $p_{ш}$ and $p^*_{ш}$ are the static and total pressure in the slot; $F_{ш}$ - the area of cross section of the slot; $\lambda_{ш}$ - coefficient of the flow velocity of the cooling air.

The pressure $p^*_{ш}$ was measured in the receiver 1, and the resistance of the channel 2-3 was considered by means of preliminary calibration (Fig. 1). Here $\bar{p} = \frac{p_{ш}}{p_{охл}}$.

The method of the processing of the results of this experiment has certain pecularities. It is generally accepted to determine the local losses as $\xi_i = 1 - \frac{\lambda_i}{\lambda_{it}}$, where $\lambda_{it} = f\left(\frac{p_i}{p^*_m}\right)$. Here, understood usually by p^*_m is the total pressure in front of the airfoil cascades p^*_0. In our case, when the theoretical flow rate of air through the cascade G_m is not equal to the flow rate of the basic air G_0 owing to the introduction of additional $G_{охл}$, this assumption is not acceptable. The determination of p^*_m was produced on the basis of the following reasonings. The cooling air, in the actual case blown through the slot, is conditionally passed through the interblade channel together with the main air (G_0) when $p_{охл} = p_0$ and $T_{охл} = T_0$. Then the increase in the air flow rate from G_0 to $G_m = G_0 + G_{охл}$ through the constant section F_0 with constant density ρ_0 leads to an increase $\frac{G_m}{G_0} = (1 + \bar{G}_{np})$ times in the flow velocity of the air and $(1 + \bar{G}_{np})^2$ times in the magnitude of dynamic head. In this case the total pressure before the cascade is the sought p^*_m i.e.,

$$p^*_m = p_0 + \frac{\rho_0 G_0^2 (1 + \bar{G}_{np})^2}{2},$$

and after transformation we finally obtain

$$p^*_m = p_0 [1 + 0{,}5 k M_0^2 (1 + \bar{G}_{np})^2],$$

where k is the isentropic index; M_0 - the Mach number before the cascade;

$$\bar{G}_{np} = \frac{G_{охл}}{G_0} = \frac{p^*_{ш} q(\lambda_{ш}) F_{ш} \sqrt{T^*_0}}{p^*_0 q(\lambda_0) F_0 \sqrt{T^*_{ш}}}.$$

Otherwise in the processing of experimental data, the generally accepted method is used. In connection with the large volume of works, the calculation was produced on the digital computer "Promin'" for which a special program was compiled.

The averaging of the parameters necessary for the construction of the resultant graphs was produced according to the momentum, i.e., the loss factor in the nozzle cascade

$$\xi_1 = \frac{\int_0^t \xi_i p_i^* q(\lambda_i) \sin \alpha_i \, dt}{\int_0^t p_i^* q(\lambda_i) \sin \alpha_i \, dt},$$

where p_i^* is the local total pressure behind the cascade; λ_i - the local velocity coefficient behind the cascade; α_i - local outlet angle of flow;

$$\operatorname{arctg} \alpha_1 = \frac{\int_0^t \lambda_z p_i^* q(\lambda_i) \sin \alpha_i \, dt}{\int_0^t \lambda_u p_i^* q(\lambda_i) \sin \alpha_i \, dt},$$

here λ_z and λ_u are the projections of the velocity coefficient on the z and u axes.

The numerators and denominators of these expressions are obtained by graphical integration.

Figure 2 shows the change in the angle α_1 and velocity coefficient λ_1 along the relative step $\bar{t}$ for different magnitudes of the given flow rate of the air $\bar{G}_{np}$. From the graphs given, it is evident that the effect of the cooling air on the flow behind the cascade is extended to a comparatively small zone, near the outlet openings.

The concluding results of the processing of the experimental data are given on Fig. 3, where plotted along the axis of the abscissa are the values of the normalized flow of the cooling air and along the axis of the ordinates, the loss factor ξ_1 in the nozzle cascade averaged with respect to the step.

On the basis of the obtained experimental data, the internal

efficiency of the turbine stage η_c with the loss ~~x~~ factor in the working cascade $\xi_2 = 0{,}079$ is calculated. The dependence of η_c on $\bar{G}_{np}$ (Fig. 4) is determined by the nature of the curves $\alpha_1 = f_1(\bar{G}_{np})$ and $\xi_1 = f_2(\bar{G}_{np})$. From Fig. 4 it is evident that the effect of the blowing in of the cooling air on losses in the nozzle ring cascade is comparatively little: with an increase in the relative flow rate of the cooling air from 0 to 0.02 the quantity η_c is somewhat increased, and a further increase in ~~thx~~ the air flow rate leads to a decrease in the efficiency of the turbine stage. Such a regularity indicates the positive effect of the cooling air in small quantities when it blows away the boundary layer on the concave surface near the outlet edge. With a sufficiently large quantity of cooling air $(\bar{G}_{np} > 0{,}02)$, the structure of the main flow undergoes an ~~x~~ unfavorable distortion, and, apparently, separation phenomena are developed, which leads to an increase in the losses of energy.

The effect of the relative flow of the cooling air on the efficiency of the turbine stage should subsequently be refined by conducting a test of the ~~np~~ nozzle cascade at actual temperatures of the gas and cooling air.

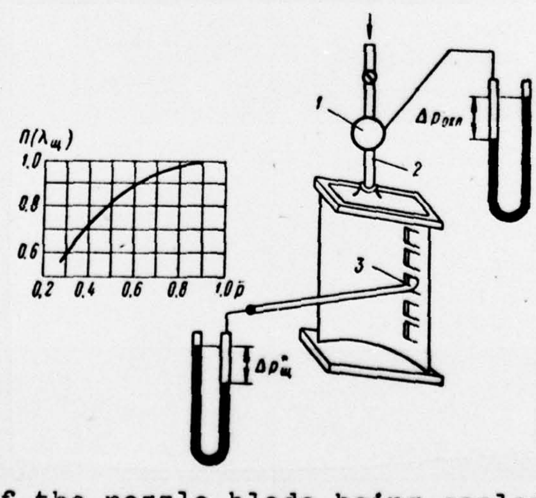

Fig. 1. Diagram of the nozzle blade being cooled: 1 - receiver of cooling air; 2 - channel of feed of cooling air; 3 - tube for measurement of total pressure of cooling air.

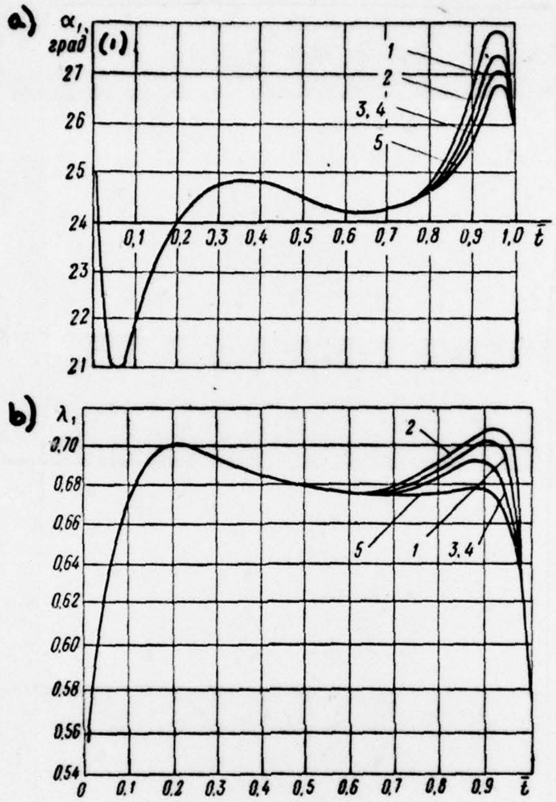

Fig. 2. Change in the angle α_1 (a) and velocity coefficient λ_1 (b) **ян** along the relative pitch of the nozzle cascade at different values of $\bar{G}_{пр}$: 1 - 0; 2 - 0.099; 3 - 0.0199; 4 - 0.0273; 5 - 0.0317. KEY: 1) degree.

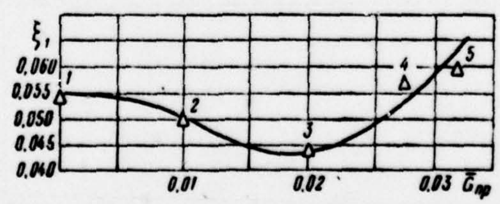

Fig. 3. Dependence of the loss factor of the cascade on the relative flow of the cooling air.

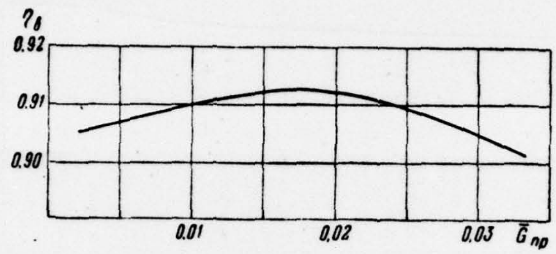

Fig. 4. Dependence of the internal efficiency of the turbine stage on the normalized flow of the cooling air.

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